POSSIBILITY OF A MOLTEN LAYER IN GANYMEDE. Y. Yamagishi and K. Kurita, *Department of Earth and Planetary Physics, University of Tokyo, Yayoi 2-11-16, Bunkyo, Tokyo 113, Japan, yamagisi@geoph.s.u-tokyo.ac.jp*.

Ganymede, the largest icy satellite, has several attractive problems; one is the evidence of resurfacing and volume expansion on its surface, another is existence of magnetic field, recently clarified by the Galileo mission [1,2]. The source region of the resurfacing material is suggested to be a water layer beneath the surface ice crust, and to generate the magnetic field, Ganymede must have a molten region where the dynamo motion is possible. To consider these features, the evolution of the internal structure of the satellite is a key. The aim of this study is to obtain possible locations of the molten layer and to estimate their life time based on the simulation. We propose the detailed picture of the thermal evolution of Ganymede starting from the differentiated structure having a vast water mantle state by solving the phase change problem coupled with connection of the different heat transportaion.

The initial structure of the satellite is assumed to be composed of two layers; the liquid pure-H_2O mantle around a solid rock core [3,4]. As Ganymede cools, two ice layers are developed in the H_2O mantle. One grows from the top, which is composed of ice-I, and another grows from the bottom, which is of high pressure phase ices. It is assumed that the heat source is only the decay energy of long-lived radiogenic isotopes in the core, ^{238}U, ^{235}U, ^{232}Th and ^{40}K. Tidal dissipation energy is not taken into account. The heat transport in the liquid region is controlled by convection and in the solid region by conduction alone. Parametrized convection is adopted for calculation of the change of the mean temperature in convective regions. To consider the freezing and the melting of the H_2O mantle, it is necessary to solve a phase change problem. Here, the ice-water interface is treated as an ordinary Stefan problem.

We suppose that the core is composed of mixture of silicate and pure-iron and that long-lived radiogenic isotopes are contained only in the silicate, which are assumed to exist at the abundance of the ordinary chondritic values. Several cases are calculated with different Fe mass fraction (f_{Fe}=Fe/(Fe+Silicate)).

Our results show three possible locations for the molten region in Ganymede through its history. The regions are as follows; the inner-ocean between the ice-I crust and the high pressure ice layer, the deeper-ocean between the high pressure ice layer and the silicate/iron core and a molten inner core.

The decay energy of the radiogenic isotopes in the core causes a deeper-ocean on the core surface. When the heat coming from the core increases, the surplus heat is consumed to melt the bottom of the high pressure ice layer in stead of heating up the ice mantle. This implies that the existence of the deeper-ocean acts to decouple the thermal state of the core and the mantle and keeps the temperature of the core surface at the melting point of the high-pressure ice. The thickness of the deeper-ocean, however, is kept very thin; order of several tens of meters in our calculations, because the surplus heat is relatively smaller than the latent heat that is needed

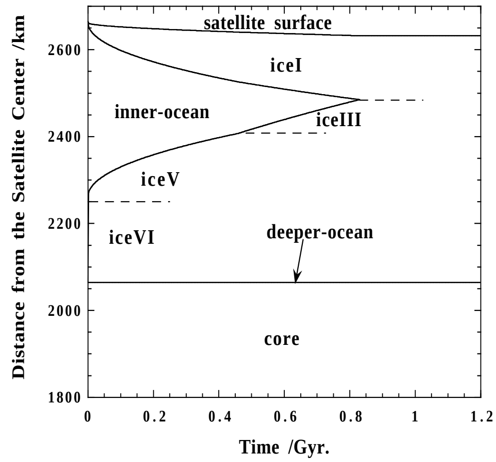

Figure 1: Evolution of the internal structure of H_2O-mantle with f_{Fe}=0.0

for melting. As far as our parameter range is concerned, the deeper-ocean appears at very early stage and exists throughout the satellite history.

The life time of the inner-ocean is about 0.8 Gyr. for any case of the Fe content in the core and do not depend on the amounts of heat generating elements because of the thermal decoupling between the mantle and the core. Within the parameter ranges tested here, the inner-ocean is completely frozen by present.

In the core, from our calculation, the temperature can rise highly enough to melt the pure iron and silicate in it. Figure 2 shows the temperature profiles in the core with the Fe content of 30 wt%. In the Figure, the maximum temperature in the core can exceed the melting point of pure iron after 3 Gyr. If the iron content is larger than 30 wt%, the temperature in the core cannot exceed the melting point. There is trade off between iron content and the maximum temperature in the core. The core is possibly differentiated into Fe inner core and silicate outer core and the differentiation occurs at comparatively later stage of its history. If complete diferentiation of the core occurs, the ineer core radius is between about 690 km and 972 km. It can be concluded that Ganymede has suffered two-stage differentiation events; ice-silicate/iron separation at first and silicate-iron separation at the later stage.

When the core is differentiated to the Fe inner-core and the silicate outer core, the heat source elements move to the outer portion since they concentrate in silicate. The inner-core is heated from the outer portion, then it will be a thermaly stable state and cannot cool. Since the outer core is large enough to have long conduction relaxation time and contain sufficient abundance of the radiogenic isotopes, the core has

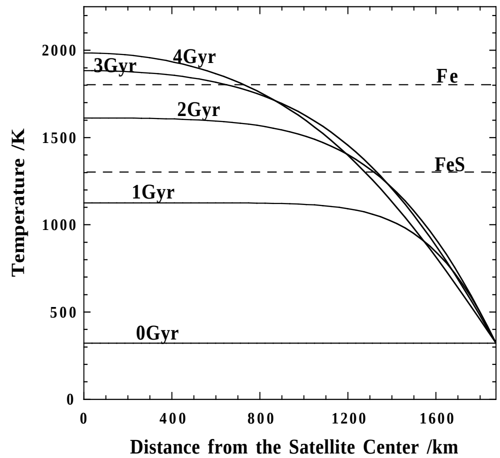

Figure 2: Temperature profiles in the core with the mass fraction of Fe in the core of 30wt%

not yet entered into the cooling stage. Therefore, it is probable that present Ganymede still has a molten Fe inner core.

The inner-ocean would be a source region for the resurfacing material. Our simulation indicates that the life time is no longer than 1 Gyr., and resultingly the phenomena should have occurred within the first 1 Gyr. If the geological evidences which favor for the more recent occurrence are available, we should consider different situations. One possibility is existence of other volatile components such as CH_4 and NH_3 in the water mantle. This causes to lower the melting point and the prolonged life time of the inner-ocean may be expected thought the details strongly depend on the phase diagram. Another possibility is existence of tidal dissipation as a heat source.

To generate the magnetic field in Ganymede by dynamo, a molten layer in the satellite is necessary where the dynamo motion is possible. Among three molten layers, only the deeper-ocean and the inner core can survive until now. The deeper-ocean is expected to be strongly convecting, but its thickness is so thin. The thickness may be larger if the core transports heat so efficiently. As for the electrical conductivity of this layer, which is an another factor to control the dynamo [5], high value can be expected, because a large amount of ions can dissolve from the silicate materials since this layer is in contact with the silicate core at high pressure and temperature. As for the inner core, we suggest the temperature sufficiently exceeds the melting temperature of iron or iron-sulfide system. This is another possible site for the dynamo action. We, however, expect that the Rayleigh number in the molten iron layer is not very high, because the inner core is heated from above, it may even have gravitationaly-stabilized stratification.

References: [1]Kivelson, M. G. el al., *SCIENCE*, *273*, 337-340, 1996. [2]Kivelson, M. G. el al., *SCIENCE*, *274*, 396-398, 1996. [3]J. I. Lunine and D. J. Stevenson, *ICARUS*, *52*, 14-39, 1982. [4]K. Kuramoto and T. Matsui, *J. Geophys. Res.*, *99*, 21,183-21,200, 1994. [5]J. S. Kargel and G. J. Consolmagno, *Proc. Lunar Planet. Sci. Conf.*, *27th.*, 643-644, 1996.